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A Study on the Deteriorating Air Quality due to Diesel Buses and the Potential of a Direct Exhaust Gas Capture System as a Solution

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Abstract: This study investigates the issue of excessive emissions and its impact in educational environments, by analysing the characteristics of three commonly used buses in the UAE—Ashok Leyland Falcon, Tata Elanza, and Toyota Coaster—such as their fuel types, fuel composition, engine specifications, and exhaust systems. This research also quantifies emissions of key pollutants such as CO_2, NO_x, particulate matter (PM), and unburnt hydrocarbons. Engine configurations and in-built emission control technologies (such as EGR, DPF, or SCR) and emission standards such as Euro 4 are studied to assess their effectiveness in reducing harmful exhaust outputs. Emission measurements were sourced from manufacturer data, certified emission tests, and field observations. The paper concludes by evaluating the environmental impact of each model, and proposing a flue-gas treatment system to ensure sustainable school transport.

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I. INTRODUCTION

The inspiration for this study came from our own experiences while traversing the bus bay everyday to board our buses, where the combination of hot weather and polluted air often made it difficult to breathe and left behind a choking sensation. These everyday encounters with poor air quality sparked a strong desire and motivation to explore a largely overlooked source of pollution coming from buses.

Every morning in Dubai, thousands of buses set out to carry children safely to their schools and the public to their workplaces. But while these buses are travelling what often goes unnoticed is the hidden danger coming from their exhaust pipes. Popular bus models in the UAE like Ashok Leyland Falcon, Toyota Coaster and Tata Elanza often run on diesel or biodiesel. This means that with every trip, they release harmful gases and particles into the air, including carbon dioxide (CO_2), nitrogen oxides (NOx), carbon monoxide (CO), sulfur dioxide (SO_2), fine particulate matter ($PM_{2.5}$), volatile organic compounds (VOCs).

Fine particles ($PM_{2.5}$) can reach deep into the lungs and often carry cancer causing chemicals. NOx makes breathing problems worse and adds to smog, while SO_2 can lead to acid rain. Carbon monoxide from idling buses reduces the body's ability to carry oxygen, and lead exposure, even in small amounts, harms brain development.

Children are the most at risk. At bus stops and depots, where engines often idle, the air becomes heavily concentrated with exhaust fumes. Research shows that diesel exhaust alone is responsible for more than 70% of the cancer risk linked to urban air pollution. This means that something as ordinary as the daily bus ride to school is quietly adding to a serious public health challenge in the city. The central problem this study addresses is how to purify the air released from school bus engines, reducing harmful emissions and protecting the health of children. The daily exposure of students to these harmful gases highlights the urgency in tackling this matter.

(Shao, S., et al. (2021).) (Morawska, L., et al. (2017), (California Air Resources Board. (n.d.).)

II. MATERIALS AND METHODS

To analyze the problem, pollutant profiles from commonly used diesel and biodiesel school buses were examined, with reference to reported concentration ranges and controlled laboratory studies.

Fine particulate matter ($PM_{2.5}$) penetrates deep into children's developing lungs, often carrying carcinogenic hydrocarbons (BTEX, PAHs), and is linked to asthma, lung cancer, and cardiovascular disease. NOx (100–500 ppm in flue gas) worsens respiratory illnesses and contributes to smog, while SO_2 emissions—on the order of 20.96 mg per

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gram adsorbed by TiO_2 nanomaterials in controlled settings—can dissolve to form acid rain. CO (up to 1,054 ppm per m³/hr from idling buses) impedes oxygen delivery in the blood, while heavy metals like Pb can accumulate at rates exceeding 90 mg per gram in nanoparticle adsorbents. (Shao, S., et al. (2021).)

These values and case studies were used as reference points for identifying the most harmful pollutants from bus exhaust and for comparing them against emerging mitigation technologies.

➢ *Cause for Emissions:*

Upon discussing with the bus drivers at our school, we suspected three main sources from which emissions were being generated by the bus. They were the AC system, the Coolant in the engines and the Diesel Fuel used by the buses.

We surveyed the buses in our school and found that the majority of the fleet consists of Ashok Leyland Falcon Euro IV buses, followed by Tata Elanza and Toyota Coaster buses. So, we looked at the average amount of fuel consumption by the buses in different time frames and with AC on and off.

Table 1 Fuel Consumption Per Minute / 30minutes / 60 minutes by a Euro IV bus Engine Based on the Bus's AC and Movement

Condition	**Fuel consumption per minute**	**Fuel consumption per 30 minutes**	**Fuel consumption per 60 minutes**
Idling (AC off)	0.04L	1.2L	2.4L
Idling (AC on)	0.058L	1.75L	3.5L
Driving (AC off)	0.15L	4.5L	9.0L
Driving (AC on)	0.172L	5.15L	10.3L

When the bus is idling with the AC off, the engine runs at 0 or near 0 RPM with no AC compressor load. When the AC is on during idling, there is an additional load on the AC compressor. Similarly, when the bus is at average city speed with AC off and on, there is a 15% increase in fuel consumption (based on fuel consumption per hour) from the former to the latter. Therefore, it can be concluded that though AC systems account for a certain percentage of emissions, they aren't the major source due to comparatively lower percentages, and their emissions are caused due to fuel consumption itself. (Mercedes-Benz Trucks. (n.d.).) (Yuchai. (n.d.)) (FilterTime. (2021).) (U.S. Environmental Protection Agency. (n.d.).), (Valvoline. (n.d.).)

Apart from that, we found out that coolants don't contribute to emissions, as in the case of a well-functioning and well-maintained engine, they neither leak nor decompose considerably to add to the poisonous emissions.

Therefore, leaving the fuel in the engine accounts for virtually 100% of emissions made.

➢ *Bus Models and Fuel Types in GMA and Dubai Schools:*

The school transport fleets in Dubai, including those serving GEMS Modern Academy (GMA), operate a mix of old and new bus models. The Ashok Leyland *Falcon* is particularly well-known for its value for money, low maintenance costs, and robust design. Other models in operation include the Tata Elanza and Toyota Coaster, which are smaller buses. (as earlier mentioned in the 'Cause for Emissions')

These buses primarily operate using diesel engines. While most schools use regular diesel, some schools have adopted biodiesel blends, with GMA specifically using *Neutral Fuels* biodiesel, derived from recycled cooking oil, which can replace diesel without any modifications to existing engines. This biodiesel is often supplied as B20, a blend containing 20% Fatty Acid Methyl Esters (FAME) and 80% petroleum diesel. Regular diesel is also still in use, consisting primarily of 75% saturated hydrocarbons (paraffins and cycloparaffins) and 25% aromatic hydrocarbons such as PAHs and BTEX. (Neutral Fuels. (n.d.).), (Khaleej Times. (2023, March 20)), (ZevRoss. (2023).)

(Note: Not all Ashok Leyland Falcon buses have identical engines. Some meet Euro 3 specifications, while others meet Euro 4 standards, depending on whether Electronic Fuel Injection systems are installed. Therefore, to avoid confusion, we have collected data and made calculations based on the Euro IV bus.)

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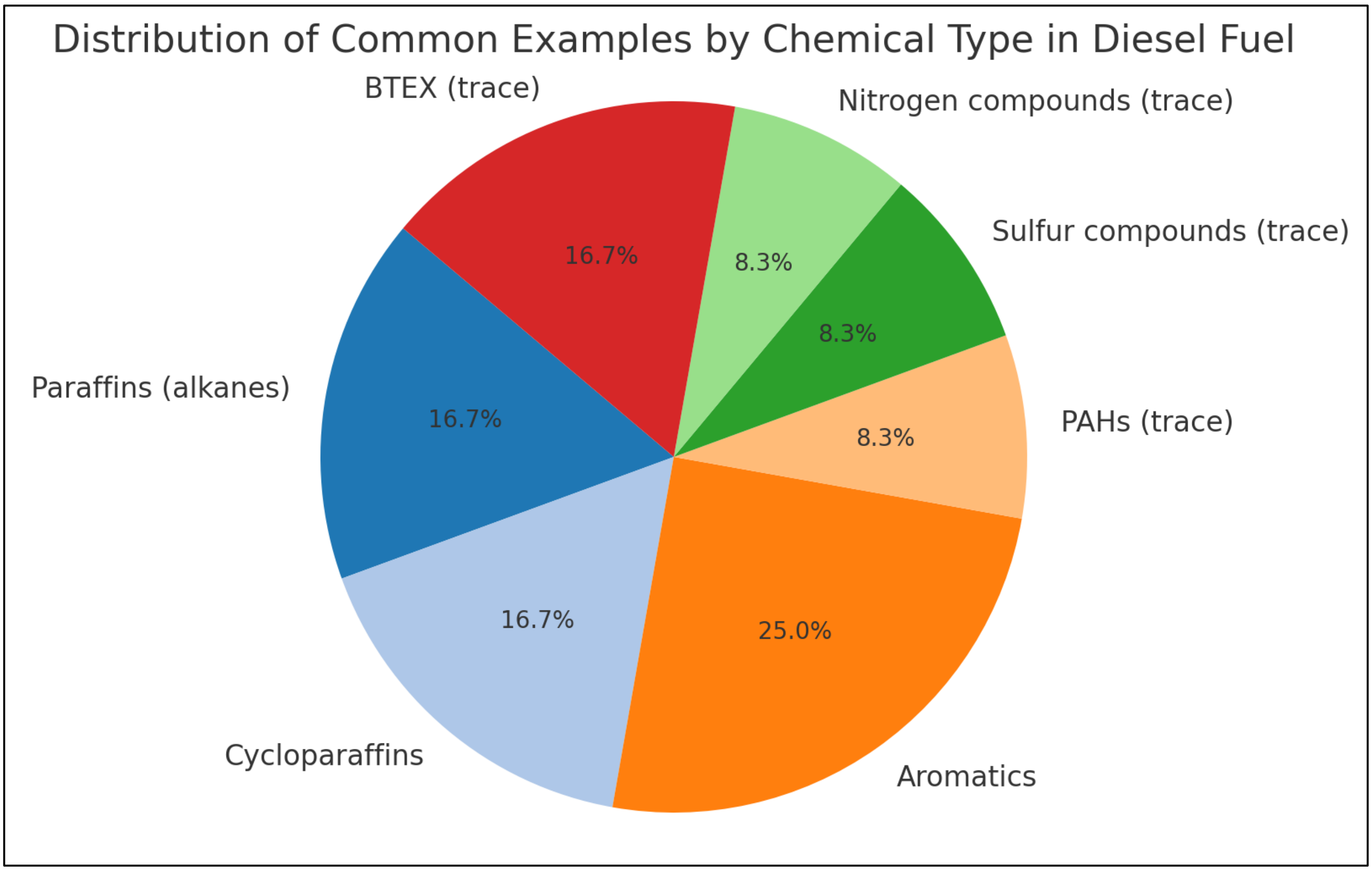

Fig 1 Showing the Composition of Different Compounds in Diesel Fuel.

The Biodiesel used generally results in lower emissions of soot/PM (Particulate Matter), CO, HC, and SOx compared to pure diesel, although it can cause a slight increase in NOx emissions. Particulate matter and aromatic hydrocarbons are linked to increased rates of lung cancer. BTEX and PAHs are classified as human carcinogens associated with leukemia, lung cancer, and neurological effects. NOx and SOx aggravate respiratory illnesses. (Morawska, L., et al. (2017).

The Ashok Leyland buses comply with Euro IV emission regulations, which define strict limits on pollutants: (Yuchai. (n.d.)

Table 2 The Table Shows the Maximum Allowed Emissions for a Euro IV Bus Engine (g/km).

Pollutant	**Euro IV limit (g/km)**
CO	≤ 0.5
NOx	≤ 0.25
HC + NOx	≤ 0.3
PM	≤ 0.025

(DieselNet. (n.d.). *Diesel particulate matter (DPM)), (Demirbas, A. (2011).), (*Neutral Fuels. (n.d.).)

- *Combustion Chemistry of Diesel and Biodiesel:*

The differences in emissions are explained by fuel chemistry.

- Diesel (approx. $C_{12}H_{23}$) combusts as: C12H23+17.75O2→12CO2+11.5H2O$C_{12}H_{23} + 17.75\ O_2 \rightarrow 12\ CO_2 + 11.5\ H_2O$C12H23+17.75O2→12CO2 +11.5H2O
- Biodiesel (C_{14}–C_{24} methyl esters, e.g., methyl oleate $C_{17}H_{33}COOCH_3$) burns similarly but contains oxygen atoms in its molecular structure. This intrinsic oxygen allows more complete combustion and results in: Lower particulate matter (PM), fewer sulphur oxides (SOx), Lower unburnt hydrocarbons. Therefore, biodiesel directly reduces harmful tailpipe pollutants without requiring engine modifications.

(Demirbas, A. (2011).), (ScienceDirect. (n.d.).), (Khaleej Times. (2023, March 20))

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Table 3 The Table Summarizes Baseline Emissions Per Kilogram and Per Liter of Diesel Fuel, Along with Emissions from B20 Biodiesel Blend

Pollutant	Baseline - g per kg fuel	Baseline g / L	B20 (ICCT modern) - g / L	B20 (NREL vehicle avg) - g / L
CO_2	3.17 g/kg	~2670 g/L	~2620 g/L (Natural Resources Canada)	-
NO_x	24.05 g/kg	20.0096 g/L	20.809984 g/L.	20.1296576 g/L.
PM (≈$PM_{2.5}$)	0.46 g/kg	0.38272 g/L	0.38272 g/L.	0.31995392 g/L. -
CO	5.65 g/kg	4.7008 g/L	5.17088 g/L.	3.8969632 g/L.
NMVOC	0.65 g/kg	0.5408 g/L	0.578656 g/L.	0.4780672 g/L.
Pb/Metals	~0, *below detection*	-	0	-
H_2O	-	0.97 kg/L	Not ICCT: 0.97 kg/L	-

We started conducting our literature research for different materials and methodologies used to filter out pollutants, especially CO2, NOx, CO, PM and VOC that were emitted from flue gas.

(Yuchai. (n.d.)), (DieselNet. (n.d.). *Diesel particulate matter (DPM)), (*Neutral Fuels. (n.d.).), (ScienceDirect. (n.d.).)

➢ *Idle Fuel Consumption and Costs:*

One of the most significant findings of this study was the extent of fuel wasted during idling. Based on Table 1, a bus idling for 40 minutes consumes approximately 2.32 L of fuel, equivalent to AED 6.26–6.72 at B20 biodiesel prices (AED 2.70–2.90/L). Over 200 school days, this amounts to 464 L wasted annually per bus, or 46,400 L for a fleet of 100 buses. The associated financial loss is AED 125,280–134,560 per year, while the environmental burden corresponds to nearly 129 tonnes of avoidable CO_2 emissions (calculated at ~2.68 kg CO_2 per liter of diesel). These results highlight idling as a major source of both economic inefficiency and environmental harm in school transport operations (Demirbas, A. (2011).)

➢ *Operational Patterns of School Buses:*

From surveys conducted primarily in GEMS Modern Academy, Dubai, we observed that:

- A typical round trip (school → student homes → return) takes ~1 hour 10 minutes, covering 30–40 km.
- Fuel usage depends mainly on mileage and AC load, not passenger count.
- Air conditioning increases fuel consumption by ~15% compared to driving without AC.
- Buses consume 30–40 L/day, meaning the fleet as a whole burns 3000-4000 L/day.
- And they consume 15L of diesel per hour (as per RTA buses).

Over 200 school days, this equals 600,000–800,000 L/year of fuel consumed by the fleet.

Switching even partially to B20 biodiesel could cut lifecycle CO_2 emissions by ~180-250 tonnes/year, while maintaining existing bus infrastructure.

➢ *Material Analysis*

To evaluate the effectiveness of various air purification strategies, we conducted a literature research of the most recommended biological, chemical, and physical methods for pollutant removal. Our research focused on widely studied substances and techniques, including algae, activated carbon, metal-organic frameworks, titanium dioxide, chemical oxidizers, and filtration systems. For each method, we examined pollutant removal efficiency, operational requirements, and associated costs. Based on this analysis, we identified the most effective approaches for targeting specific pollutants such as CO_2, NOx, CO, SO_2, particulate matter, lead, and volatile organic compounds. The following table summarizes our findings, highlighting the potential of each substances.

Table 4 The Data in the Table Indicates the Effectiveness of Each Method in Removing or Reducing Specific air Pollutants Under Standard or Optimized Conditions. (Percentages are Given Based on Average Atmospheric Pollutant Concentrations Unless Mentioned Otherwise)

	CO2	NOx	CO	SO2	PM	Pb	VOC
Scenedesmus Dimorphus	10 - 20% and 75.61% CO2 utilisation efficiency when there is intermittent sparging of flue gas and a pH control feedback system	100 - 500 ppm NO	2.07mg/L per hour 1,054ppm CO2 per hour per m³	100 ppm	638.13mg/L/d = approximately 0.638ppm/h.	(Inhibits algal growth and isn't absorbed)	78% absorption efficiency under certain conditions.

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Chlorella Vulgaris (grown in catholyte at 25 - 30 C) => sequester CO_2 and generate power in microbial carbon capture cells	80% absorption in ideal cases	Upto 97% removal (when experimented with flue gas concentrations of (30 - 780 ppm)		Uptake is indirect via aqueous phase sulphate compounds (Dissolution to H_2SO_3 → oxidation to H_2SO_4 → sulfate ion uptake)	-	(high in water)	-
Activated Charcoal	Its adsorption Gets compensated for by so2		banana peel-derived, $ZnCl_2$-activated, or microwave-modified carbon can reach up to 97.6% CO removal (when activated carbon is impregnated with metals like Cu, Fe, or Ag), it CO chemisorption increases	-	-	-	Adsorption capacities for VOCs like acetone and ethyl acetate range from 33–277mg/g, with higher values seen for more surface-tailored carbons.
Titanium dioxide	In nanoparticle-enhanced solutions, expect a 50% increase over baseline CO_2 absorption rates (exact ppm/hour depends on baseline solvent and conditions). In photocatalysis, TiO_2 can convert CO_2 at rates on the order of micromoles per gram catalyst per hour, which translates to several ppm decrease in closed systems	About 3 micromoles NOx removal per 10 cm^2 per hour, Which can be scaled to around 90 mg NOx per m^2 per day (from other studies), Or, for practical purposes, about 3 mg NOx per m^2 per hour under these conditions with 1 ppm NOx concentration	TiO_2 is not a good photocatalyst for CO oxidation without dopants or co-catalysts.	consider standard conditions and typical gas flow rates around 100 mL/min (0.1 L/min), 20.96 mg of SO_2 absorbed per gram of TiO_2 over roughly 1 hour		roughly 95 mg of lead can be adsorbed per gram of titanium dioxide nanoparticles under optimal conditions	92.7% removal in 200min at high TiO_2 dose 1–$10\times10^{-5}s^{-1}$ (kinetic models) Fast initial adsorption, strongly enhanced by UV light

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	over an hour.	and adequate UV light.					
KMnO4	No direct absorption	~540 ppm/hr	Potassium permanganate alone has a limited and poorly defined capacity for CO removal, but becomes highly effective and rapid when combined with catalysts like silver or mercuric ions. The value is not readily available at the moment.	~5.4 - 53.4 mg SO2 / g KMnO4 over ~60 minutes	Not directly applicable / Indirect removal by oxidation of dissolved species	Effective lead oxidation at KMnO4 dosages about 1-5 mg/L corresponding to removal rates >90% within ~1 hour.	*range between 7.0x10^-8 to 2.0x10^-6 cm/s in vapor phase.*
NaOH	1.443 $mol/min\cdot m^2$	No absorption /Possible with NaClO2 catalyst but very slow reaction otherwise.	No absorption (Very slow rate)	3.8×10^{-3} mol/L·s	No absorption	Reacts only at the correct temperature and in the presence of a catalyst.	No absorption
NaClO2	No absorption	$1.4 \times 10^6 (L/mol)^3 s^{-1}$ (NO)	No absorption	$5.57 (kmol/m^3)^{-1} \cdot s^{-1}$	No absorption	No absorption	No absorption
DEF	Negligible absorption	*Variable data, however already implemented in EURO IV vehicles for extremely high NOx absorption efficiency*	No absorption	No absorption	No absorption	No absorption	No absorption
Metal-Organic Frameworks	1.**CALF-20**: 7.8 mol/kg at 1 bar; >80% absorption in ideal conditions 2.Mg-MOF-74: 9.9 mmol/g at 1 bar;	1. MFM-300(V): 13.0 mmol/g at 1 bar 2.UiO-66-NH2: 3.5-4.2 mmol/g 3.MIL-125-	1. CuBTC (HKUST-1): Up to 11 mol/kg at 40 bar 2.MIL-100(Fe): 0.38-2.78 mol/kg at 1	1.MFM-101: 18.7 mmol/g at 1 bar 2.MFM-190(F): 18.3 mmol/g at 1 bar 3.SNFSIX-Cu-TPA: 2.22	1.Mg-MOF-74@PAN: >99.5% filtration efficiency for $PM_{0.3}$ 2.UiO-66@Cellulose: ~99.99%	1.Zn-MOF with O^- groups: 616.64 mg/g 2.Cu-DPA MOF: 99.5% removal efficiency	1.HKUST-1@PVA: varies depending on VOC type 2.MIL-68@PVA: varies

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	3.3. Al-TCPB(OH): 0.52 mmol/g under humid conditions	NH_2: 2.8-3.6 mmol/g	bar 3. MOF-177: 4.64 mol/kg at 1.08 bar	mmol/g at 0.002 bar	PM removal efficiency 3.MOF-801/PVDF: 64-88% $PM_{2.5}$ removal efficiency	3.DUT-67: 98.5 mg Pb^{2+}/g MOF	depending on VOC type except CH3COOH 3.bio-MOF-11: 0.73-3.57 mmol/g depending on VOC type 4. MIL-125-NH_2 had a toluene removal efficiency for >80%
Electrostatic Precipitator	—	Up to 38% using a special fitter. Plasma/catalyst retrofit, or honeycomb single-stage ESP at high voltage.	—	Generally ineffective for SO_2 gas, slight effect only for particle-bound forms; <20% for true gas	Up to 99% for wide PM sizes with correct dust resistivity; 90–98% for typical PM	if lead is PM-bound, removal rate is similar: up to 99%	-
Cyclonic Separation	99%; using Bottom ash adsorbent bed	UPTO 90% using Selective catalytic reduction.	<10% to negligible pollutant removal	Only for large, coarse PM-bound lead; not for vapor or small particles; 70–98% if PM >10 µm	Coarse PM efficiency: 70–98% for PM >10 µm; 20–70% for $PM_{2.5}$; much lower for <2 µm		-
Hepa Filtration	43% efficiency ; Deep-bed activated carbon or potassium hydroxide (KOH) impregnated filter media.	41% with special filter media; Potassium hydroxide (KOH) or chemically enhanced carbon filter media.	<10% pollutant removal	Ineffective for gas-phase SO_2; only removes if attached to PM	≥99.97% removal for ≥0.3 µm PM in lab; 20–70%+ real removal in homes. Removes tiny and large PM; smaller and larger than 0.3 µm caught at even higher rates.	Only effective if lead is attached to PM; for typical PM-bound lead, ≥99.97% for ≥0.3 µm particles	-
ZnH-mfu-200 4I	>96% initial adsorption capacity at temperatures above C	–	-	-	-	-	-

LiOH	LiOH showed 28% CO_2 absorption in the first minute under experimental conditions. Higher temperatures (90-120°C) are similar to vehicle exhaust conditions. $2LiOH + CO2 \rightarrow Li2CO3 + H2O$	-	-	Not optimal	-	-	-
Mesoporous MgO	Mesoporous MgO when promoted by double sodium salts ($NaNO_2$ and Na_2CO_3) exhibits an absorption capacity of 12.7 mmol/g at 325 C in a dry CO_2 stream and 11.5mmol/g at 275 C in a wet CO2 stream	-	-				minimal

(if '-' is mentioned, it means that reliable data for the given parameter)

(He, J., et al. (2024).), (U.S. Environmental Protection Agency. (1998).), (Southwest Research Institute. (n.d.).), (U.S. Environmental Protection Agency. (2017).), (Kumar, A., et al. (2021)), (Kumar, R., et al. (2025)), (Verma, S. K., Tripathi, P., & Bhatnagar, A. (2023)), (Rohde, R., Carsch, K., Long, J., et al. (2024)), (Zhao, X., Xu, X., Zhang, G., Zhan, W., Tang, Y., & Li, C. (2018)), (U.S. Environmental Protection Agency. (2025, March 3).), (ScienceDirect Topics. (n.d.). - Exhaust temperature an overview), (Ingale, Y., Rathi, R., Ali, Y., Salve, S., & Khelkar, S. (2023)), (Kodo, Kodo, & Tsuruoka, 2000), (The Affordable Organic Store, n.d.), (Society of Chemical Industry, 2023), (Desrousseaux & Liger-Belair, 2020), (United States Department of Energy, 2018), (Vieira, de Souza, & Freitas, 2023), (Mississippi State University, 2010), (All About Feed, 2021), (ScienceDirect Topics, n.d.), (Number Analytics, 2022), Tibbetts & Mann, 2020)

- *Most Prevalent Physical Emission Control Technologies:*

Table 5 Some of the Most Popular Emission Control Methodologies Used

Emission Control Technology	Pollutant Targeted	Working Principle
Selective Catalytic Reduction (SCR)	NOx	Injects reductant (urea) to convert NOx into N2 + H2O
Diesel Particulate Filter (DPF)	Particulate Matter (PM)	Traps soot particles and periodically burns them off
Three-Way Catalysts (TWC)	NOx, CO, HC	Catalyzes oxidation and reduction reactions simultaneously
Lean NOx Trap (LNT)	NOxh	Adsorbs and reduces NOx under cycling conditions
Exhaust Gas Recirculation (EGR)	NOx	Recirculates exhaust gas to lower combustion temperature
Oxidation Catalysts	CO, HC	Oxidizes CO and hydrocarbons into CO2 and water

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➢ *Cost Per Unit Substance:*

Table 6 Table List the Substance or Method and Lists the Corresponding Cost

Substance / Method	**Cost of using per g/kg (for substances) or of installing per kW capacity/type/application (for method)**
Electrostatic Precipitators	(highly expensive and load heavy)
Cyclonic Seperation	50,000 - 2L inr (2,500 - 10,000 aed)
HEPA Filtration	10,000 - 20,000 inr (500 - 1000 aed) only for filter element
Metal Organic Frameworks	UiO-66-NH_2 - 650 inr/g ~ 650,000 inr /1kg (27300 aed) Mg-MOF-74 - 300 inr/g ~ 300,000 inr/ 1kg (12600aed) CALF-20 - 29USD/kg - 106.5 aed/kg, 2522/kg
LiOH	8000-12000 USD/ METRIC TON ~ 8-12 USD/ kg (30-44 aed)
NaOH	42 aed/ 5 kg ~ 8.4 aed/ kg
KMnO4	35 USD/ 500g ~ 70 USD/ kg (257 aed)
TiO2	65 aed/ 100g ~ 650 aed/ kg
NaClO2	88 aed/ 500g ~ 176 aed/ kg
DEF	72 aed/ 10L ~ 7.2 aed/ L
Activated Charcoal	1429 aed/kg (supplementary charcoal) and 11.45 aed for 100cm x 50cm
Chlorella Vulgaris	296 aed/kg
Scenedesmus Dimorphus	835 inr/ 50ml ~ 16600 inr/ 1L (696 aed)

(U.S. Environmental Protection Agency, 2023), (Indiamart, 2024), (Indiamart, 2024), (Sigma-Aldrich, 2024), (CIFAR, 2023), (Trading Economics, 2024), (Noon, 2024), (Sigma-Aldrich, 2024), (Amazon.ae, 2024), (Sigma-Aldrich, 2024), (Adnoc, 2024), (The Affordable Organic Store, 2024), (Alibaba, 2024), (Blue Green Labs, 2023).

Hierarchy of Pollutant removal efficiency (made using Table 4)

Table 7 Table Lists the Best Substances for Removing Each Pollutant.

	CO2	**CO**	**SO2**	**VOC**	**PM**	**NOx**	**Pb and heavy metals**
1st	NaOH	Activated Charcoal	MFM-101	TiO2	HEPA	DEF	Electrostatic Precipitators
2nd	CALF-20	CuBTC (HKUST-1)	MFM-190(F)	Activated Charcoal	Electrostatic Precipitators	NaClO2	HEPA Filtration
3rd	Chlorella Vulgaris	MOF-177	SNFSIX-Cu-TPA	bio-MOF-11	Molecular Sieve	Chlorella Vulgaris	Cu-DPA MOF
	Cyclonic Separation	MIL-100(Fe)	HEPA	Scenedesmus Dimorphus	UiO-66@Cellulose	KMnO4	TiO2
	HEPA	Scenedesmus Dimorphus	KMnO4	KMnO4	Mg-MOF-74@PAN	Cyclonic Separation	Zn-MOF with O^- groups
	Scenedesmus Dimorphus	HEPA	Cyclonic Separation	HKUST-1@PVA	Cyclonic Separation	HEPA	KMnO4
	LiOH	Cyclonic Separation	TiO2	bio-MOF-11	MOF-801/PVDF	Electrostatic Precipitators	NaOH

(Southwest Research Institute. (n.d.).), (U.S. Environmental Protection Agency. (2017).), (Kumar, A., et al. (2021)), (Kumar, R., et al. (2025))

➢ *Our Solution - Pavan:*

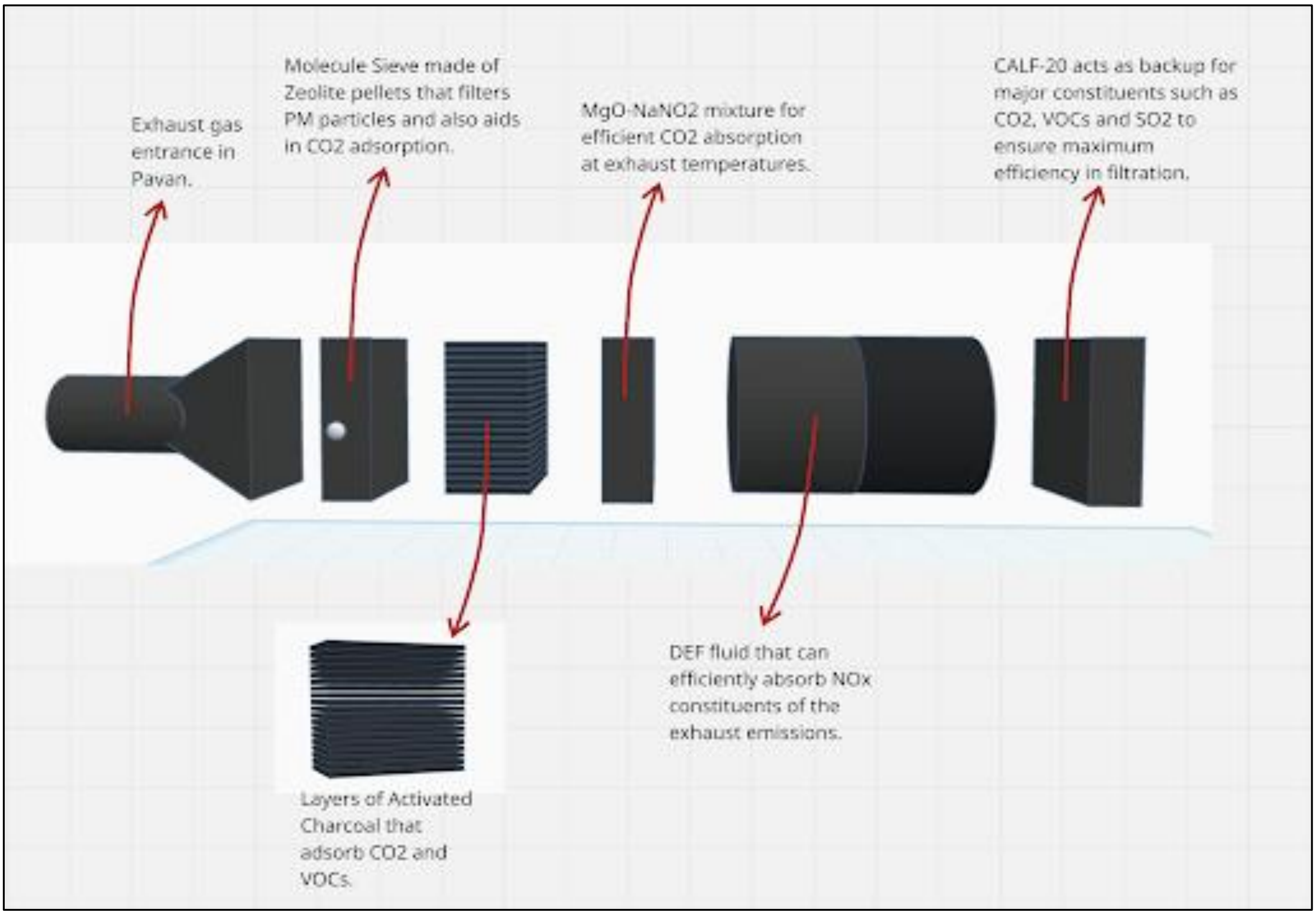

Fig 2 Modular Part-by-Part Diagram of Pavan

➢ *Function of Each Module:*

Zeolite pellets filters out PM And other Large Particles in the flue gas, Activated charcoal adsorbs VOC's, CO and other odor causing pollutants, MgO-NaNO$_2$ mixture absorbs CO_2 and small quantities of NOx and VOC's, DEF SCR liquid is setup for NOx absorption and CALF-20 - is installed as a backup for CO_2 and VOC absorption.

The first layer, through which the exhaust gas of the bus passes, is a molecular sieve made of zeolite spheres. As air is forced to navigate through the gaps between these spheres, larger and heavier PM particles are caught in the sieve. These are one of the most dangerous constituents of exhaust gases. Zeolite also aids in CO_2 removal as it adsorbs CO_2 to its surface. The gas then passes through stacked layers of activated charcoal sheets. Activated charcoal adsorbs CO_2 as well as VOCs.

Next, the air passes through the MgO-NaNO$_3$ mixture that absorbs a large quantity of CO_2 through chemical reactions (note: its ideal temperature for reaction is maintained by the hot exhaust emissions that are of a similar temperature). After that, the CO_2 and PM purified gas enters the DEF fluid chamber that absorbs a large quantity of NOx constituents present in the exhaust emissions. And finally, the gas passes through a final layer of CALF-20 which is a metal organic framework that absorbs the remainder of CO_2, SO_2 and VOC's as thereby greatly reducing the overall emissions from the exhaust.

(Note: CALF-20 can also absorb trace quantities of SO_2 present in the gas)

Additional features about Pavan are that it will be made modular i.e. each layer can be interacted with independently. Essentially, the entire system will utilize a drawer like mechanism allowing each layer to be separated from the rest and therefore allow for easy maintenance or replacement of chemicals or a damaged module thereby keeping running costs at a minimum, and that an external covering of Fiberglass, internally coated with Silicon carbide, will be used to handle the average exhaust temperatures (200-300^{o}C) with ease whilst not compromising on necessary strength as the bus moves around.

Moreover, the parts have been designated in such an order such that MgO-NaNO$_2$ dominates the CO_2 reduction (however for it a regeneration strategy is required) and that there is a backup substance for the removal of each major pollutant in case of any unforeseen situation.

This is slightly similar to the Direct Air Capture method used for atmospheric carbon capture. However, unlike DAC, Our system proves to quite effective for this purpose as the

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CO_2 concentration of the exhaust flue gas is very high and we directly capture the exhaust gases from the exhaust pipe.

This can also be confirmed from (Rana et al, 2025) that the substances we are using for Pavan are the most effective of the commercially available CO_2 absorbing/adsorbing substances for this task

(He, J., et al. (2024).), (U.S. Environmental Protection Agency. (1998).), (Southwest Research Institute. (n.d.).), (U.S. Environmental Protection Agency. (2017).), (Kumar, A., et al. (2021)), (Kumar, R., et al. (2025)), (Verma, S. K., Tripathi, P., & Bhatnagar, A. (2023)), (Rohde, R., Carsch, K., Long, J., et al. (2024)), (Zhao, X., Xu, X., Zhang, G., Zhan, W., Tang, Y., & Li, C. (2018)), (U.S. Environmental Protection Agency. (2025, March 3).), (ScienceDirect Topics. (n.d.). - Exhaust temperature an overview), (Ingale, Y., Rathi, R., Ali, Y., Salve, S., & Khelkar, S. (2023))

III. RESULTS

Based on a Laboratory report from the laboratory of the National Communications Academy, Ghaziabad (Erstwhile NTIPRIT),

Considering the Exhaust flow to be 1000 L/min = 60 m³/h,

- *Exhaust Gas Composition (Inlet, Baseline):*

Table 8 Baseline Inline Exhaust Gas Composition of Major Pollutants

CO_2	NO_x	SO_2	CO	PM 2.5
40,000 ppm	1,000 ppm	200 ppm	1,000 ppm	500 µg/m³

- *The Target Reductions (on Percentage Basis) in the Expected Case is:*

Table 9 Expected Pollutant Reductions Upon Implementation of Pavan

CO_2	NO_x	SO_2	CO	PM 2.5
70%	95%	80%	95%	95%

- *Predicted Outlet Concentrations are:*

Table 10 Comparison of Pollutant Concentration Between the Flue Gas Before Entering Pavan and After Exiting Pavan

Pollutant	Inlet	Removal (%)	Outlet
CO_2	40,000 ppm	70%	12,000 ppm
NOx	1,000 ppm	95%	50 ppm
SO_2	200 ppm	80%	40 ppm
CO	1,000 ppm	95%	50 ppm
$PM_{2.5}$	500 µg/m³	95%	25 µg/m³

- *The Sorbent Demand Calculations (per 8-hour Operation) are:*

Table 11 Sorbent Demand Calculations (per 8-hour Operation)

Module	Calculation Basis	Requirement (8h)
CO_2 – NaOH	70 mol/h CO_2 × 2 mol NaOH = 5.6 kg/h	≈45 kg
CO_2 – CALF-20	0.25 g CO_2/g sorbent; 7 mol/h = 308 g/h	≈10 kg (regenerable)
NOx – DEF	95% removal of 2.5 mol/h = 1.2 mol urea/h	≈0.6 kg (urea solution)
SO_2 – NaOH	0.4 mol/h SO_2 × 2 mol NaOH = 32 g/h	covered by NaOH
CO – Activated Carbon	67 g/h at 100 mg/g capacity	≈5.5 kg (regenerable)
$PM_{2.5}$ – ESP/HEPA	30 mg/h load × 95% = 28.5 mg/h	Captured on filters

- *From this it Can be Said that for Every 480000 L of Flue Gas (1000L * 480 Minutes) the Given Masses of Substances are Required:*

Table 12 Mass of Each Substance Required for 8-Hour Performance for Exhaust Pollutants Being Emitted at a Rate of 1000L Gas/min

Material	Approx. Mass
NaOH pellets/solution	45 kg
CALF-20 (MOF)	10 kg (regenerable)
DEF (urea solution)	0.6 kg
Activated carbon	5.5 kg (regenerable)
Filter media/ESP plates	Low load (service item)

(Note: Values scale linearly with flow (e.g., double for 2000 L/min))

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(Note: due to this excessive weight of NaOH required for the CO_2 removal, we have substituted it with MgO mixed with $NaNO_3$, that is nearly equally effective per unit mass than NaOH, and when it is converted to $MgCO_3$, it can be used for several versatile applications such as anti-caking agents, and drying agents that can be sold to respective consumers)

Table 13 Brief Comparison between NaOH and MgO

	NaOH	**MgO (for wet CO2 absorption at 275 °C)**
Rate of absorption of CO_2	70 mol / 5.6 kg	70 mol / 6.08 kg
Change of Rate of absorption	No change with temperature or pressure change	Increases with increase in temperature upto a limit

The other issue with NaOH is that upon reaction it forms Na_2CO_3 and H_2O which could form a solution and thus cause leaking. Therefore, we have decided not to use it despite its cheap cost and high efficiency.

IV. CONCLUSION

This analysis of the air pollution caused by buses, specifically school buses in Dubai, highlighted how grievous air pollution is. Its highly detrimental impacts on human health, especially children, tend to make our educational environments and workplaces highly toxic. To solve this we came up with Pavan, a feasible solution to this issue that reduces high percentages of pollutants from the exhaust flue gas of these buses and virtually any diesel operating vehicle via substances such as Zeolite pellets, MgO, activated carbon, CALF-20 MOF, DEF-SER achieve predicted outlet levels of 12,000 ppm CO2, 50 ppm NOx and 25 µg/m³ netting around 75-90% removal goals, offering some of the highest control in the market. Therefore, results highlight that retrofitting existing Euro IV buses with Pavan can significantly mitigate the health burden from school transport emissions.

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